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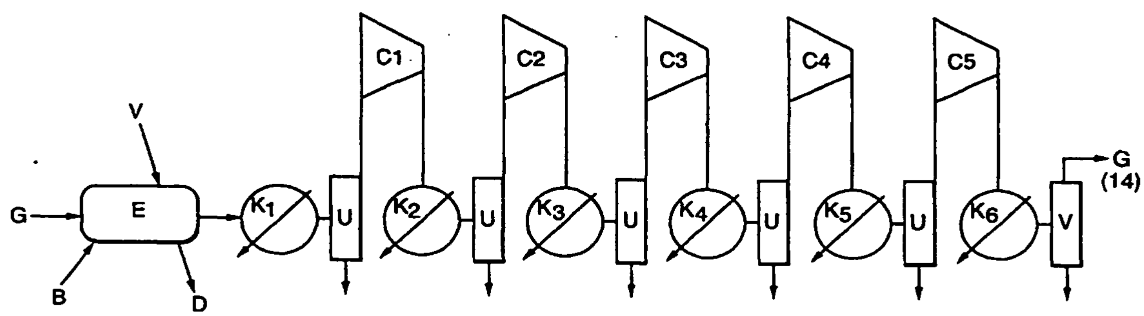


(57) Abstract

In order to reduce discharge of environmentally harmful gases, particularly $CO_2$, hot exhaust gas (G) from gas turbines used on oil recovery installations is injected into the oil reservoir, upon having passed through an afterburner/heat recovery assembly (E) and compressor equipment ($C_1 - C_5$) in which the $O_2$ content of the exhaust gas is reduced to desired level. Heat energy recovered by the afterburner/heat recovery assembly (E) is preferably used for operating the compressor equipment ($C_1 - C_5$).

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# SYSTEM FOR THE PRODUCTION OF POWER/HEAT ON AN OIL INSTALLATION, AND METHOD AND APPARATUS FOR THE HANDLING OF HOT EXHAUST GASES FROM GAS TURBINES.

The present invention relates to a system for the production of power/heat on an oil installation, and a method and apparatus for handling the exhaust gases from gas turbines at oil recovery installations.

Normally, the exhaust gases from such gas turbines are admitted directly to the atmosphere, possibly after flare burning for reducing remaining hydrocarbons or other inflammable substances that are decomposed into substantially steam and $CO_2$. In view of the increasing global concern about pollution of the atmosphere ("the greenhouse effect"), such effluents are environmentally very undesirable, since it is a matter of large amounts of effluent in the order of four billions $m^3$ or more per year from each single installation. There is therefore a need within the art of oil recovery to find a relatively economic solution of this pollution problem.

Under certain conditions during oil recovery the natural gas that usually is produced together with the oil (associated gas) is partly or entirely reinjected into the reservoir. The purpose of such injections would be to retain the pressure of the reservoir in order to facilitate the oil recovery. In recent years, however, also associated gas has increasingly been commercially utilised, resulting in a correspondingly lower amount of gas available for enhancing the reservoir pressure.

The principal object of the invention is, therefore, to provide a solution of the above pollution problem, permitting a substantial reduction of the amount of environmentally harmful gases, including $CO_2$, discharged to the atmosphere, while also permitting control of the formation pressure with less consumption of natural gas.

This object is achieved according to the invention, by subjecting at least part of the exhaust gases to an afterburning process in which the $O_2$ content of the gas is reduced, and in which the heat energy developed during the afterburning process is utilised through heat recovery, followed by compressing the gas and injecting it into the reservoir, such as more specifically stated in the appending patent claims.

The purpose of the afterburning is primarily to reduce the O2 content of the exhaust gases to a desired, relatively low level. This is because the exhaust gas, which normally is relatively rich in oxygen exposes the production equipment to a corrosive environment when injected into the reservoir. Also, the energy demand and consequently the cost for carrying out the injection process are relatively high, since the exhaust gas to be injected has to be compressed up to required injection pressure, of the order of 150 – 400 bar.

Thus, the invention builds on the acknowledgement that by permitting the hot exhaust gas from the gas turbine to pass through an afterburner, the O2 content of the gas may be reduced to a value that is adapted to the reservoir conditions at various oil fields of interest, while the energy demand for operating the injection equipment (compressors etc.) partly or entirely is covered by utilising the exhaust gas heat energy, including the combustion heat of the afterburning process.

The invention will now be explained in more detail with reference to the appending drawings, of which fig. 1 shows a system or flow diagram of a possible embodiment of an apparatus according to the invention, and fig. 2 shows a flow diagram of a modified embodiment of the apparatus according to fig. 1.

Referring to fig. 1, the hot exhaust gas G from an gas turbine (not shown), normally an axial gas turbine (open system) is passed to a combined afterburner/heat recovery assembly E (briefly referred to as "the combination assembly" in the following description), supplied with supplemental fuel (oil, gas) B for the afterburning process, if necessary. According to requirements, means for increasing the pressure, such as a blower, may be located up-streams of or included in the combination assembly E in order to ensure that the gas turbine back pressure does not reach such a high level that the turbine efficiency is substantially reduced. Preferably, the combination assembly E is comprised of a steam boiler with water supply V and steam outlet D as indicated in fig. 1, in which the afterburning takes place in the boiler firing means. Gas exiting the latter is passed through an aftercooler $K_1$ followed by preferable a plurality, such as five, compressor stages, $C_1$-$C_5$, via intercoolers $K_2$-$K_5$ and optionally endcooler $K_6$ with associated condensed water separators U, whereupon the exhaust gas is injected into

the reservoir in a traditional manner via a separate injection well or directly into the producing well, at the appropriate injection pressure.

According to the invention the oxygen content of the exhaust gas, which normally would be in the range of 12 – 14 percent by volume, is reduced during the afterburning process to a desired level, normally between 0,25 and 7 percent by volume, dependent on the reservoir conditions.

Although energy recovered from the combination assembly E may of course be utilised in whatever desirable application, preferably it will be used in the compressor work to raise the exhaust gas pressure to the required injection pressure level.

The prime movers for driving the respective compressors $C_{1-5}$ can of course be selected among several possible alternatives such as steam turbine, gas turbine or electric motor, depending on what is considered to provide optimum operation at the prevailing conditions.

In some cases it may be desirable to reinject, partly or entirely, the gaseous fraction of the fluids produced from the well, together with the exhaust gas G. Such gaseous fraction, apart from associated gas, will normally, to a larger or smaller extent, contain previously injected exhaust gases. The flow diagram of fig. 2 illustrates a modification of the apparatus according to fig. 1, adapted to such gas reinjection. Here the gaseous fraction g is preferably passed through a cooler $K_7$ with a condensate separator U and mixed with the turbine exhaust gas G at an appropriate location where the pressure of the latter is equal to or somewhat lower than the pressure of the produced gaseous fraction g, e.g. between compressors $C_1$ and $C_2$.

Three data-simulated examples of practical applications of the invention in connection with offshore oil recovery, using the apparatus shown in the figures, are given below. The examples are based on an assumed total injection exhaust gas amount of 1,7 x $10^9$ $Sm^3$/year (4,9 x $10^6$ $Sm^3$/day for 350 days of operation per year) from a gas turbine, e.g. of the type LN2500 with combicycle. The exhaust gas from the turbine will have a temperature of about 550°C and a pressure of about 1 bar. The O2 content of the exhaust gas is assumed to be about 12 %, and the combination assembly E to be used is a steam boiler, suitably adapted for use in connection with the invention.

**Example 1** (Fig. 1)

In steam boiler E the temperature increases to 1650°C and then falls to about 150°C. The afterburning process is controlled in a manner to reduce the oxygen content of the exhaust gas to a desired level, normally about 1 % but with a possible variation range up to 7 % maximum. The control is carried out, if necessary, by varying added heat, i.e. additional fuel B; the more additional fuel, the lower should be the content of the exhaust gas G from the boiler E. In aftercooler $K_1$ the temperature further falls to about 30°C. Then the exhaust gas pressure gradually increases through compressors $C_1 - C_5$ from about atmospheric pressure (1 bar) to about 5; 16; 53; 97; and 175 bar (the injection pressure), respectively, with intercooling $K_1 - K_5$ down to about 25°C between each compressor, whereupon the gas is injected into the reservoir via an injection well, preferably after having passed through a scrubber. At this stage the gas is preferably maintained above the dew point to avoid corrosion problems in the injection well. Optionally, additional cooling could be performed in an end cooler $K_6$, if desirable owing to limitations on the design temperature of the injection riser/well.

**Example 2** (Fig. 2)

Here, all the gas produced from the reservoir (associated gas + previously injected exhaust gas) is reinjected together with the exhaust gas from the turbine. The injection demand at the time during the lifetime of the field the example refers to is $8 \times 10^6$ $Sm^3$/day, of which $3 \times 10^6$ comes from the reservoir and mainly consists of previously injected exhaust gas. This implies necessary addition of about $5 \times 10^3$ $SM^3$/day net exhaust gas, corresponding to the amount of exhaust gas from the gas turbine. The gas g from the reservoir is added to the turbine exhaust gas G between the two first compressors $C_1$, $C_2$ as shown in fig. 2, while otherwise the apparatus is the same as in example 1 (fig. 1).

**Example 3** (Fig. 2)

Also in this example all of the gas g that is produced from the reservoir is reinjected. Here, however, a part, G', of the exhaust gas G from the gas turbine is separated from the system, e.g. to give room to the reproduced gaseous fraction g, in view of the capacity of compressors $C_1 - C_5$. The exhaust gas part G' not to

be injected can be separated upstreams of boiler E and discharged directly into the atmosphere, optionally via a separate heat recovering unit, such as a heat exchanger, but preferably it is separated after boiler E and before the first compressor $C_1$, as indicated by broken line in fig. 2, such that all of the exhaust gas G is subject to the afterburning process implying reduction of oxygen.

The injection demand at the time during the lifetime of the field for which the example is intended, is about $10^6$ $SM^3$/day, of which 8 millions comes from the reservoir and mainly consist of previously injected exhaust gas. This means that $2 \times 10^6$ $SM^3$/day net exhaust gas must be added.

The pressure levels in the recovery well can of course vary. Thus, upon a gas breakthrough the wellhead pressure may rise as high up as to 50 bar. In the above simulation examples 2 and 3 a wellhead pressure of 5 bar are assumed for all reproduced gas, which is a relatively low value. For higher wellhead pressures it may be appropriate to insert reinjected gas g in the exhaust gas G at a higher compressor stage, between compressors $C_2$ and $C_5$.

All three examples assume an added (fired) thermal power of 75 MW to the gas turbine, and a mechanical power of 26 MW in the turbine. The total thermal power of the exhaust gas G in boiler E, including added (fired) power to the latter, is assumed to be about 210 MW, which provides a computed power of about 77 MW based on the steam produced in boiler E.

Net cooling demand associated with the production of exhaust gas with 1 % oxygen is 132 MW if all of the exhaust gas from the gas turbine is reduced in oxygen to 1 %. In addition comes compressor cooling, which in example 3 is 80 MW.

The energy demands for recompression is given in the following table:

| Compressor | Dimensioned power for each compressor [MW] | Energy demand Example 1 [MW] | Energy demand Example 2 [MW] | Energy demand Example 3* [MW] |
|---|---|---|---|---|
| C1 | 16 | 15,6 | 15,6 | 7,4 |
| C2 | 21 | 10,4 | 17 | 21 |
| C3 | 22 | 10,9 | 18 | 22 |
| C4 | 10 | 5,0 | 8 | 10 |
| C5 | 10 | 5,3 | 9 | 11 |
| Sum | 79** | 47,3 | 69 | 71 |

The table shows the energy demand (power) for which the compressors are dimensioned, for an oil field, and the energy demand for the three examples.
* Example 3 refers to the dimensions for total energy demand.

**All the compressors will not run at full capacity at the same time, such that the sum in the bottom column is the maximum total power used to compress the exhaust gas and produced gas.

As appearing from the table, the total energy demand of the first compressor $C_1$ is 15,6 MW. This value is based on an efficiency of 95 %, provided that the exhaust gas from the gas turbine is passed through boiler E and compressed (examples 1 and 2). In example 3 the demand for exhaust gas to injection is reduced compared to the design criterion. Consequently this example results in 7,4 MW for that compressor. All examples assume a pressure drop of 0,2 bar between each compressor stage and after the last compressor stage, mainly because of cooling.

The last column in the table shows a power consumption at a time during the lifetime of the field when the energy demand for compression is at its highest. At that time the energy demand of 71 MW is still lower than 77 MW, which the boiler steam production is capable of providing. In this case the exhaust gas demand for injection is about 50 % of that which the gas turbine can deliver, such that the burning of the amount of exhaust gas which is sufficient for injection is capable of providing only 36 MW which is not sufficient to cover the compressor demand. Then more exhaust gas could be burned than that of the injection demand while discharging the non-injected gas into the atmosphere, or cover the

remaining power demand in different ways. At other times during the lifetime of the field the burning of sufficient amounts of exhaust gas for injection will provide enough power to compress exhaust gas and produced gas.

It is then evident that produced steam can be fully utilised. Since the assumed recompression demand is fairly low, as is also the assumed separator pressure, this implies a considerable degree of reduction potential.

The steam balance is easily adjusted by adjusting the amount of fuel B added to boiler E.

A good energy demand and production balance is achieved. However, there are also alternatives in which the entire recovery plant (platform) is supplemented with power based on steam.

This would require installation of one or two steam boilers, each of 50 MW produced mechanical energy as steam, and the exhaust gas is injected therefrom.

The process must be adjusted to the actual process configuration and updated wellhead pressure.

The invention is primarily intended for use in connection with offshore installations, but is not limited to such application.

## PATENT CLAIMS

1. System for the production of power/heat on an oil installation, in which the power is partially produced via gas turbines and in which the exhaust gas from the turbines after compression is injected into the reservoir from which oil is recovered, c h a r a c t e r i z e d by subjecting at least a portion of the exhaust gas to an afterburning process in which the $O_2$ content of the gas is reduced to a desired level, and by utilising the thermal energy of the exhaust gas particularly for operating equipment for compressing the exhaust gas.

2. Method for the disposal of hot exhaust gas (G) from gas turbines used on oil recovery installations, in which at least a portion of the hot exhaust gas is pressurised to a pressure corresponding to the pressure of the reservoir from which the oil is recovered and then injected into the reservoir, c h a r a c t e r i z e d by, prior to pressurising it, subjecting the exhaust gas (G) to an afterburning process whereby the $O_2$ content of the gas is reduced to a desired level, and by utilising the thermal energy of the exhaust gas particularly for operating the exhaust gas pressurising equipment.

3. Method according to claim 2, c h a r a c t e r i z e d by utilising a steam boiler for said heat energy utilisation, in which the afterburning process is performed in the firing means of the steam boiler.

4. Method according to claims 2 or 3, c h a r a c t e r i z e d by pressurising the exhaust gas from the afterburning process in several stages ($C_1 - C_5$) with intercooling ($K_2 - K_5$).

5. Method according to anyone of claims 2 – 4, c h a r a c t e r i z e d by adjusting the O2 content of the exhaust gas to a level between 0,25 and 7 % by adjusting the supply of fuel to the afterburning process.

6. Method according to claims 2 – 5, characterized by introducing at least a portion (g) of any gas recovered together with the oil into the exhaust gas (G) for being reinjected together with the latter.

7. Method according to claim 6, characterized by introducing recovered gas into the exhaust gas between two compressor stages ($C_1 - C_2$).

8. Method according to claim 7, characterized by diverting a part (G') of the exhaust gas to the atmosphere at a location between the afterburning process and the first compressor stage.

9. Apparatus for the disposal of hot exhaust gas from gas turbines used on oil recovery installations, comprising compressor equipment ($C_1 - C_5$) for compressing at least part of the exhaust gas to the pressure necessary for injecting said exhaust gas part into the reservoir from which the oil is recovered, characterized by a combined afterburning/heat recovery assembly (E) adapted to reduce the $O_2$ content of the exhaust gas to a desired level, and to utilise recovered heat from the exhaust gas, particularly to operate the exhaust gas compressor equipment.

10. Apparatus according to claim 9, characterized by said afterburner/heat recovery assembly (E) comprising a steam boiler.

11. Apparatus according to claim 9, characterized by said compressor equipment ($C_1 - C_5$) comprising several compressor stages with intercoolers.

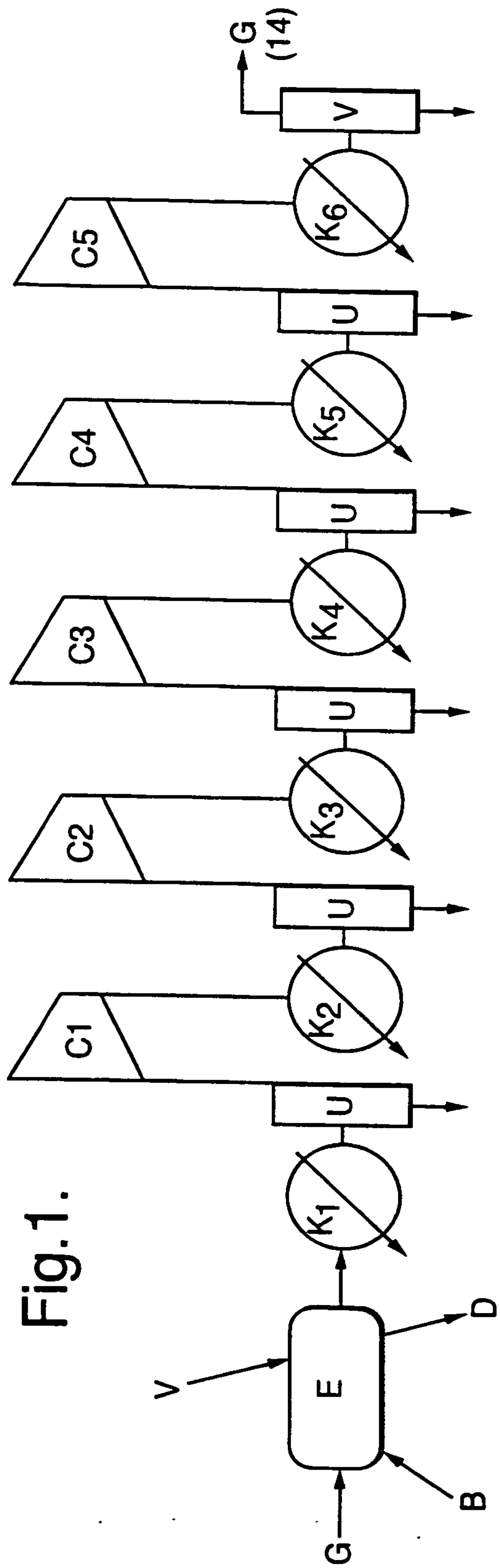
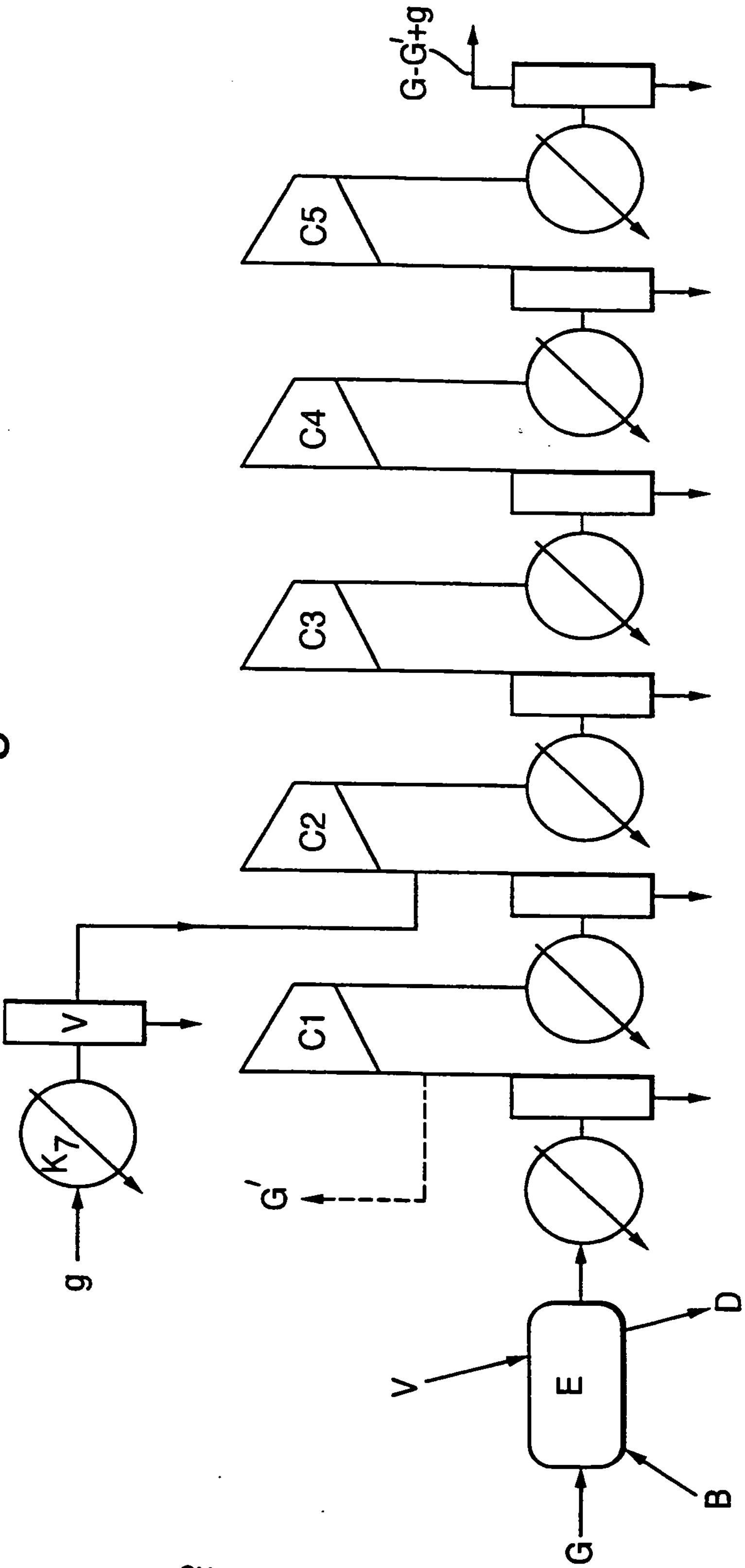



Fig.1.

Fig.2.



# INTERNATIONAL SEARCH REPORT

International application No.
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## A. CLASSIFICATION OF SUBJECT MATTER

IPC7: E21B 43/00, E21B 43/12, E21B 43/16, E21B 43/18, F02C 3/00, F02C 3/02, F02C 3/20

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## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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